ARO 22998.25-PH



# A PROGRAM OF BASIC RESEARCH FOR HIGH POWER SWITCHING AND OTHER HIGH POWER DEVICES

FINAL REPORT

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MAY 23, 1989

U.S. ARMY RESEARCH OFFICE

GRANT NUMBER: DAAG29-85-K-0240

UNIVERSITY OF SOUTHERN CALIFORNIA
DEPT. OF ELEC. ENGR.-ELECTROPHYSICS
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SECURITY CLASSIFICATION OF THIS PAGE

# REPORT DOCUMENTATION PAGE

| | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION<br>Unclassified | 1b. RESTRICTIVE MARKINGS |
| 2a. SECURITY CLASSIFICATION AUTHORITY<br>2b. DECLASSIFICATION / DOWNGRADING SCHEDULE | 3. DISTRIBUTION / AVAILABILITY OF REPORT<br>Approved for public release; distribution unlimited. |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S) | 5. MONITORING ORGANIZATION REPORT NUMBER(S)<br>ARO 22998.25-PH |
| 6a. NAME OF PERFORMING ORGANIZATION<br>University of Southern California<br>6b. OFFICE SYMBOL (If applicable) | 7a. NAME OF MONITORING ORGANIZATION<br>U. S. Army Research Office |
| 6c. ADDRESS (City, State, and ZIP Code)<br>University Park<br>Los Angeles, CA 90089-0484 | 7b. ADDRESS (City, State, and ZIP Code)<br>P. O. Box 12211<br>Research Triangle Park, NC 27709-2211 |
| 8a. NAME OF FUNDING / SPONSORING ORGANIZATION<br>U. S. Army Research Office<br>8b. OFFICE SYMBOL (If applicable) | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER<br>DAAG29-85-K-0240 |
| 8c. ADDRESS (City, State, and ZIP Code)<br>P. O. Box 12211<br>Research Triangle Park, NC 27709-2211 | 10. SOURCE OF FUNDING NUMBERS<br>PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO |

11. TITLE (Include Security Classification)

A Program of Basic Research for High Power Switching and Other High Power Devices (Unclassified)

12. PERSONAL AUTHOR(S) Gundersen, Martin A.

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT (Year, Month, Day) | 15. PAGE COUNT |
|---|---|---|---|
| Final Technical | FROM 9-1-85 TO 2-28-89 | 1989 May 23 | 10 |

16. SUPPLEMENTARY NOTATION The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation

| 17. COSATI CODES | | | 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) |
|---|---|---|---|
| FIELD | GROUP | SUB-GROUP | High power switching, high power devices, Back lighted thyratron(BLT), optoelectronic bistability |

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The study of the physics of thyratron type switches under this contract has led to a new low pressure glow discharge switch that has a number of features that are desirable for high power applications. The switch has achieved high stand-off voltage and peak current (70 kA), has very fast current rate of rise, and operates near the glow-to-arc transition in hydrogen and other gases. It appears to have intriguing scaling possibilities. In addition, we demonstrated a cold, hollow cathode that operates with much higher current densities than dispenser and oxide thermionic cathodes -- without forming an arc. Current densities that are about 2 orders of magnitude over heated cathode current densities -- 10,000 A/cm$^2$ vs. 100 A/cm$^2$ -- have been achieved over cathode areas of approximately 1 cm$^2$. 20,000 A peak current is readily achieved in a simple, unheated configuration. Finally, in a different area, an optoelectronic bistability in GaP has been observed. The bistable mechanism is based on trap filling, and has possible applications to optically integrated devices.

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| 20. DISTRIBUTION / AVAILABILITY OF ABSTRACT<br>☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS | 21. ABSTRACT SECURITY CLASSIFICATION<br>Unclassified |
| 22a. NAME OF RESPONSIBLE INDIVIDUAL | 22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL |

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

# SUMMARY OF RESEARCH FINDINGS

A low pressure glow discharge switch that has a number of features that are desirable for high power applications has been designed and operated. The switch has achieved high stand-off voltage (30 kV), and peak current (70 kA), has very fast current rate of rise, and operates near the glow-to-arc transition in hydrogen or helium. It appears to have intriguing scaling possibilities. Closure is initiated by light incident on the back of the cathode. We call it a BLT (Back-Lighted Thyratron). Surface damage within the area of illumination is less than surrounding areas, in contrast to most laser triggered switches. We have continued to develop our new high power glow discharge switch for pulsed power applications (Appl. Phys. Lett. **49**, 494 (1986)). The switch is a back-of-the-cathode light-activated thyratron type switch (BLT). This switch should be considered for applications where high power thyratrons are a limitation. The current research effort includes a detailed study of the operation of this switch directed towards optimizing switch performance. Two experimental switches have been built with removable electrodes that allow for the testing of different electrode materials and hole sizes. An experimental circuit and gas handling vacuum system has been set up and is being used to study switch operation. Peak current, maximum standoff voltage, current rate of rise, delay and jitter have been measured and show promising results.

Several interesting results have been recently obtained pertaining to hydrogen thyratrons and related plasma physics. A severe limitation of the thyratron as a high-power closing switch is the maximum repetition rate. Through a time-dependent theoretical plasma calculation and innovative experimental measurements, a much better understanding of the recovery phase of a hydrogen thyratron has been obtained. This work has shown that the atomic temperature plays a very important role in the rate of recovery. To make the required measurements, a new method appropriate for use in a hydrogen thyratron has been developed to measure the time-resolved electron density.

We have found a method for optically gating -- *opening and closing* -- a high voltage glow discharge. The switch has operated reliably at currents of the order of 20 mA, and the experiments yield information on a new method for optical control of the glow discharge.

The experimental results were obtained using a hollow electrode discharge structure, or back lighted thyratron (BLT), in parallel with a small capacitor. The discharge is initiated and extinguished by a short pulse of light from a UV flashbulb. The current is supplied by a high voltage supply through a current limiting resistor. The switch is filled with $H_2$ to about 0.5 torr and will hold off ~ 1.5kv. When the lamp is flashed once a glow discharge is initiated at 20mA with a forward drop of ~ 200v. When the lamp is flashed a second time the discharge is extinguished and the voltage returns to ~ 1.5kv.

These results demonstrated a reliable optically controlled gas opening switch. Research has established the feasibility of the BLT switch, and has also defined areas of switch studies, and applications of both the switch, and the principles upon which the switch is based. It is possible to achieve higher current, higher dI/dt, and other results (described below), in this new family of switches, which operate in a glow discharge. It has thus been possible to establish that this glow, thyratron-type switch is a candidate to replace spark gaps, and hence extend applications.

Recently this laboratory demonstrated a cold, hollow cathode that operates in thyratron type switches at *higher* currents than dispenser and oxide thermionic cathodes -- without forming an arc. Current densities that are about 2 orders of magnitude over heated cathode current densities -- 10,000 A/cm$^2$ vs. 100 A/cm$^2$ -- have been achieved over cathode areas of approximately 1 cm$^2$. 20,000 A peak current is readily achieved in a simple, unheated configuration, and it may be possible to extend performance to peak currents over 100,000 A. In addition, this cathode has demonstrated thyratron operation with greatly improved dI/dt, 100 % reverse current capability, and lower forward drop. This is an anomously high regime of operation for a cold cathode operating in a glow discharge plasma, and is of interest because in spite of the considerable phenomenological understanding of gas discharge phenomenon, these data were not predicted, and these results apparently will have important device applications. Although in the past higher but localised current densities have been achieved through the formation of filamentary arcs, devices (e.g. spark gaps) tend to be limited melting, sputtering and cratering of electrode material, and addition of electrode material to the arc plasma. This new cathode allows currents that formerly required arc-type devices, such as spark gaps.

An optoelectronic bistability in GaP has been observed. The bistable mechanism is based on trap filling, and has several possible applications. This simple bistable device can be realized using a commercial light emitting diode. The bistability is based on a negative resistance effect that can be observed in commercial GaP light emitting diodes (LEDs). An optical bistability is observed in both luminescence intensity and peak wavelength, and is produced by light incident on an electrically biased sample. The optical bistable operation with the GaP LED differs from that reported in semiconductors such as InSb, InAs, GaAs and CdHgTe, which are based on optical nonlinearity and typically use the same light for input and output. Also, the effect reported here is not a change in transmitted light intensity through a Fabry-Perot resonator due to an intensity-dependent refractive index change. The bistable states were shown to switch with an optical gating. The bistable mechanism was explained as a consequence of traps affecting the carrier characteristics (which also results in the negative resistance region of the diode I-V curve). It is also suggested that optically coupled devices may be possible in an integrated form.

The technological relevance of this work is in several important areas. These include the excimer laser industry, accelerators and beam switching applications in high energy physics, and several defense related activities. Applications to excimer lasers have generated considerable interest.

In addition to the switch work, additional applications include electron and ion beams, x-ray and microwave production, modulator development for various applications, a new superemissive cathode, applications for the cathode, and applications to plasma loaded devices such as accelerators and plasma lenses. These applications are being pursued *independently, and are not considered in detail in this report. However, the potential* impact supports the value, and encourages the further technological research and development of the present effort. As an example, the superemissive cathode produces 10,000 A/cm$^2$ over $\approx$ 1 cm$^2$. This should be compared to cathodes that are presently

considered highly emissive -- with ≈ 50 $A/cm^2$! Details that have recently been published in Physical Review Letters.

A parenthetical result is the new BLT application for high energy physics plasma lenses. The lens is based on a hollow cathode stable Z-pinch plasma that operates in a superdense glow mode, and has the following demonstrated characteristics: Current density 10 to 40 kA/cm2, plasma density $3 \times 10^{15}$ cm-3, the plasma extends very uniformly over an area of ~ 1 cm2, and the current pulse length is variable between ≈ 10 ns and 10 μs. Active focussing due to the magnetic field of the high current plasma and self focussing due to the strong radial wakefields generated in the beam-plasma interaction for a 20 Mev and 50 Gev have been analyzed.

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